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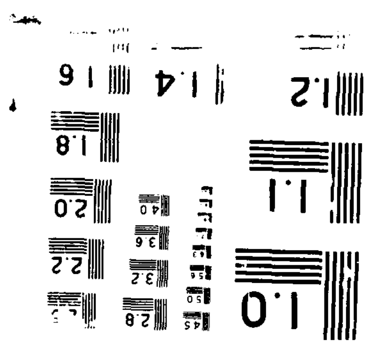

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An Investigation of ARQ and Hybrid FEC-ARQ on an Experimental High Latitude Meteor Burst Channel

By

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In this paper an investigation of error control coding techniques on an experimental northern latitude meteor burst link is presented. Bit error patterns were obtained and the performance of automatic request for retransmission (ARQ) and hybrid forward error correction (FEC) with ARQ were examined from the standpoint of probability of message delivery and encountered delays with respect to the message delivery.

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SECTION 1

INTRODUCTION

Meteor Burst Communications (MBC) is a technology that presents the opportunity for communication over the intermediate range of 200 to 1200 nautical miles. MBC allows high speed data transmission for short intervals of time, as it is dependent upon ionization trails of meteors (specks of sand and the like) entering the atmosphere for its support. Meteor burst communication is one more of the many ways that long distance radio communication is possible. It is a candidate for communication to remote sites that do not have easy access to long-haul telephone or satellite channels. Examples of such applications are communication to oil drilling rigs or Eskimo communities in the Arctic, communication between scientific stations in the Antarctic, and communication between remote jungle areas. Since meteor burst does not yield rapid interchange of data, it is only applicable to those users who have noncritical data to transmit, the kind of traffic that currently uses mailgrams where overnight delivery is satisfactory. While it is generally possible to deliver a few lines of text in ten minutes, real time data transmission is not possible.

All meteor burst channels are different. The frequency of occurrence of meteor trails is less at high latitudes than at low latitudes, and it also varies with time of year and location. Thus, any experimental analysis of meteor burst performance is applicable only to the time and place of the experiment. In this paper we examine channel error patterns and methods to mitigate them and thereby extend the possibilities for data communication. Errors are caused not by the meteor burst channel but by failures in the modulation and detection equipment employed to accurately decode the received signal. Thus, the results of any experimental study are limited by the equipment used. While this study will show how to improve the performance of meteor burst data communication, its results, which are derived of an experimental meteor burst link and modified commercial equipment, are not directly applicable to any current or envisioned system.

The MITRE Corporation has examined data from an experiment in Greenland for the purpose of expanding knowledge of the effects of channel errors on MBC performance and devising methods for investigating the mitigation of these effects through coding. While the results presented are directly applicable only to this experiment and the modified commercial equipment used, the concepts of performance improvement through coding can be applied to any real system if tests are first made with that system in its environment.

This experiment involved the operation of a test MBC link from Thule Air Base (AB) to Sondrestrom Air Base. The geographical parameters for the link are given in table 1.

Table 1. Geographical Parameters for the Experimental Path

	Sondrestrom AB	Thule AB
Longitude	50°39′	67°51′
Latitude	66°59′	76°33′
Azimuth	339°	142°

The great circle distance between the two sites is 1121 kilometers (km) and the midpath elevation for 100 km altitude (a typical altitude for a meteor trail) is 6.5° (degrees).

The experiment consisted of measuring MBC performance at 65 megahertz (MHz), using the Meteor Communications Corporation's (MCC) commercial off-the-shelf model 440 Communication Sets, which were modified to permit recording of received bit patterns. This piece of equipment is designed to permit operation of the automatic retransmission technique of channel error control that is commonly used on MBC channels. In this technique, a message is transmitted and an acknowledgment of correct receipt is returned. If the message was not correctly received, the received message is discarded and the message is retransmitted. The Model 440 Communication Sets were modified by MCC to permit all received data to be recorded for future analysis of error patterns.

The antennas used were a five-element Yagi at Thule AB and a six-element Yagi at Sondrestrom AB. The measured antenna gains at MBC elevation angles were about 11-12 decibels relative to an isotropic radiator (dBi) at both sites. The power amplifiers provided 2 kilowatts (kW) but are operated at 1 kW. Modulation was differential phase-shift keying (DPSK) and the data rate was 4800 bits/second. The information was sent using the odd-parity ASCII code. A combination of transmission time losses and a slightly worse noise environment produced an extra 5 dB loss at the Thule AB end of the link as compared to Sondrestrom AB. The data presented in this report was collected around the clock in 1/2-hour time blocks spaced 90 minutes apart. The result is a large data base from which delays, bit error rates (BERs), and bit error patterns can be calculated for all hours of the day.

This paper presents an analysis of a portion of the message traffic sent at 67.133 MHz at Sondrestrom AB and at 65.133 MHz at Thule AB. This experiment started in July 1986. The specific dates of the analysis data are given as Julian dates in 1986.

To operate the link, a test message was sent from one end of the link. If it was acknowledged, the sending end then started sending actual data messages in the form of continuous sequences of ten character packets, each preceded by a synchronization sequence. The maximum message length was 500 characters. The received bit stream was recorded and the received time was recorded with the data. If there were a nonsupporting period of time wherein the ionosphere would not permit communication, this could be seen clearly from the time tag data. Messages were transmitted in both directions depending upon channel support.

Received bit pattern data was collected and stored on magnetic tape and returned to the laboratory for analysis where the received bit pattern was compared to the transmitted pattern and the differences were identified as errors. Computer programs for coding analysis were written in FORTRAN and run on a VAX computer. Graphic results were developed on a Zeta Plotter using the DISSPLA graphics package.

Figure 1 is an illustration of some definitions of the distribution of errors as developed by P. C. Crane [1]. For this paper, the important things to note are the following: the initial error-free gap is the period when ARQ systems function, and some FEC can correct through the initial burst-free gap and thus elongate the amount of time that an overlaid ARQ system will function.

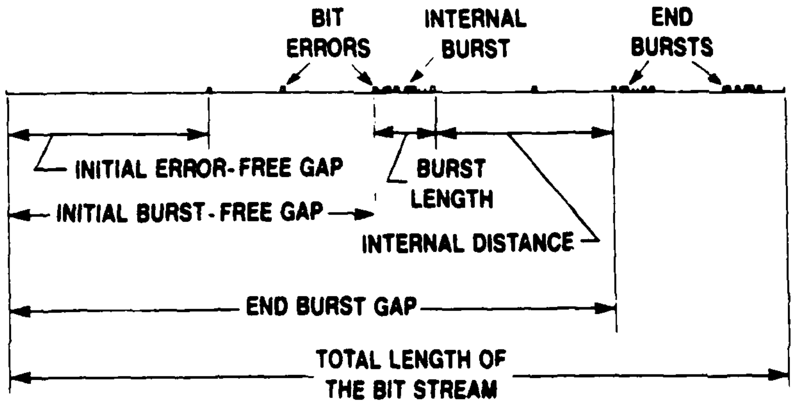

Figure 1. ILLUSTRATION OF SOME DEFINITIONS

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SECTION 2

ERROR CORRECTION STRATEGIES

We shall consider two basic strategies for dealing with channel errors. They are automatic request for retransmission (ARQ), and the use of forward error correction (FEC) with ARQ.

ARQ System Structure

Central to the design of any communication system is the basic system structure. The system to be considered herein in one where messages are divided into a finite number of fixed-length blocks, each containing information bits and error detection parity bits. These blocks are continuously transmitted from message source to message sink without any inter-block delays. On reception the blocks are checked for errors and, for any block found to be in error, a request for retransmission is issued according to its block number (a portion of the block information content). The retransmitted block is inserted in the continuous stream going from message source to message sink. It is assumed that a return communication channel exists and that this channel is error-free. This is not unreasonable, since the quantity of information on the return channel is typically small, only block number acknowledgments and retransmission requests are transmitted, and large amounts of coding for error correction can be incorporated in the retransmission request. This fact, in combination with a discipline of automatically retransmitting a block if no acknowledgment is received in a finite time, has the effect of making the return channel error-free. If high-speed, two way communications is a normal practice, the highly coded acknowledgments and retransmission requests can be interspersed with data blocks being transmitted in both directions. On the meteor burst channel, the communication is not necessarily continuous, as once a meteor trail ends, a probe signal must be transmitted to search for further channel propagation support.

Hybrid FEC-ARQ System Structure

The Hybrid FEC-ARQ system is structured in the same fashion as the pure ARQ system, with one change. That is, the number of bits used for error detection parity is increased and used for both error correction and detection. When a message block is received it is first processed through a bit error corrector that, using a portion of the error control capability of the system, corrects some bit errors and reduces the error rate. The received blocks are then processed through the error detection stage, which uses the remainder of the error control capability to detect blocks in error. Since some of the errors have been corrected, fewer blocks will be retransmitted and the time required to deliver a message will be reduced.

Automatic repeat request systems and hybrid systems combining ARQ with forward error correction using shared redundancy can be designed to provide a specified probability of successfully delivering a message from message source to message sink in a given maximum amount of time [2].

Hybrid FEC-ARQ is a necessary approach to communication when ARQ alone cannot meet a system's maximum delivery time performance requirement, or when the ARQ design technique results in a block length less than that which the user wants due to constraints on noncommunication parts of his system. Hybrid FEC-ARQ can also be used to achieve a higher probability of successful message delivery and/or shorter delivery time than would be achieved by ARQ only. In meteor burst communication, this last goal is the one that is sought.

Block Coding

One class of error correction codes is known as block codes [3]. There are many different types of block codes, but they all have the following properties:

1. A particular code word length (in bits). We shall denote this length by n.

2. A code rate. The code rate (R) is given by R=k/n where k is the number of information bits contained within the code word. Therefore, there are n-k additional bits appended to every block of k information bits for the purpose of error correction. This means that the length of the user message will be increased by 1/R. From the standpoint of minimal overhead, the closer the code rate gets to one, the better.

3. The number of bit errors in a code word that the code will correct. We shall denote this number by t.

Codes are specified by the ordered pair (n,k). In this study, we will confine ourselves to Bose-Chandhuri-Hocquenhem (BCH) codes of various code rates. For these codes, as k decreases with respect to n, t increases. This is, however, balanced by the decrease in R. Thus, the code corrects more errors but its associated overhead reduces the available transmission time on the channel.

FEC will extend the length of the usable bit stream beyond the initial error-free gap as long as the BER is low enough for the selected code to correct the errors. On the data collected, the BER in the initial burst-free gap was found to be typically on the order of .01. This implies that a high rate code will suffice in this region of the bit stream. Once an error burst is encountered, however, the BER within the burst (the burst density) will be quite high, and a more powerful, lower rate, and, therefore, more overhead-intensive code will be required. Burst densities are typically .3 to .6, which would require quite a low code rate. Hence, it appears that FEC will probably require the message to fit into the initial burst-free gap.

SECTION 3

MODULATION CONSIDERATIONS

DPSK modulation is a technique whereby the decision as to whether a pulse is a "1" or a "0" is based on whether the phase of the pulse has shifted significantly from the phase of the previous pulse. This has the advantage of requiring that only a change in phase be detected and does not require that the actual phase be determined.

An unfortunate characteristic of DPSK modulation is a significant tendency for bit errors to occur in pairs. This is especially true for the fairly low error-rate and relatively high signal to noise ratio (SNR) operation that normally occurs in the burst-free gaps. Here, the bit errors in this portion of the bit stream are likely to be caused by a noise spike of such short duration that they distort the signal's phase completely during a single pulse. Since the following pulse uses the distorted pulse as a phase reference, a high likelihood exists that both binary decisions will be in error. In fact, in the data sets that were analyzed, errors occurred in the burst-free gaps in groups of two more than 99 percent of the time. This DPSK modulation characteristic is especially annoying if one is attempting to use FEC, as the code must be powerful enough to deal with two bit errors in a given code word. This, of course, forces one to use a lower rate code than the BER would indicate.

Let us assume that the second bit error in each bit error doublet can be removed and the remaining bit stream analyzed for performance using ARQ and a variety of BCH codes. Consulting figure 2, we see that the removal is approximately equivalent to operating a coherent PSK system 1 or 2 dB below what is required for DPSK operation -- at least in the burst-free gaps where the error rates are fairly low. For example, suppose that one

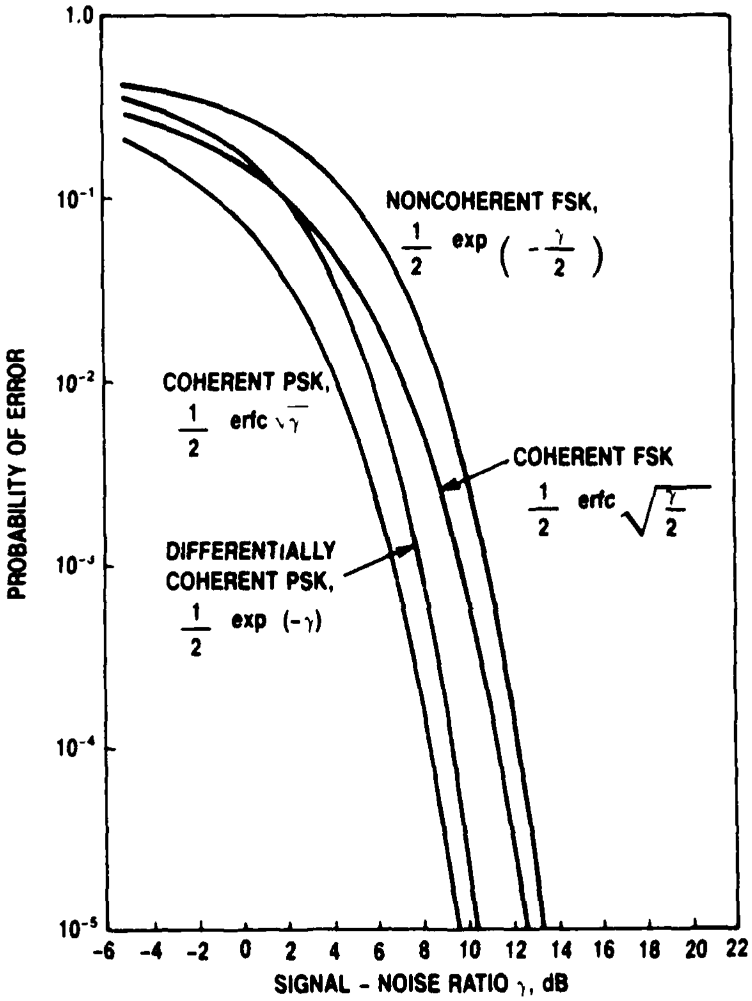

Figure 2. ERROR RATES FOR SEVERAL BINARY SYSTEMS

has a BER of 10^{-3} using DPSK. This would require an SNR ratio of about 8 dB. Removal of the second bit error in each doublet would reduce the BER to 5×10^{-4} and would require an SNR of about 7 dB if one were using coherent PSK modulation, 10 dB if coherent FSK were used, or 12 dB for noncoherent FSK.

SECTION 4

PERFORMANCE RESULTS

As has been previously shown [2], a key statistic for measuring the performance of ARQ and Hybrid FEC-ARQ systems is the probability of successfully delivering a message in at most a given amount of time. This is what the customer for such a system wants to know. Traditionally, engineers have used the parameter of throughput which tells what fraction of the channel's capacity is being used. While this is useful for analysis, it is a parameter that has no meaning in the business world. On a meteor burst channel, where the channel is not available much of the time, throughput becomes totally meaningless and only the time to deliver a message is of any use. All the results in this paper are presented in terms of the cumulative frequency of occurrence of message delivery in at most a given amount of time. The data has been evaluated to include delivery of all possible messages, which never took more than ten minutes. Thus, by normalizing the values on any curve to that curve's maximum value, the probability distribution function is obtained. The reader can then apply the previously developed [2] mathematical theory of ARQ and Hybrid FEC-ARQ to evaluate variations in operating parameters.

The recordings of traffic consisted of sequences of received error streams, each with a time tag. To determine the time delay for message delivery, we start at the beginning of the data stream and seek to deliver a message of the stated number of bits. If an error occurs in the bit span, we return a negative acknowledgment and try again. We space over times when there was no active meteor trail but we include the time in between trails in our analysis. Each time a message is delivered we record its total time including all retransmissions and channel idle time, add it to our statistical results, and start over from the next bit in the data stream. We consider our sample size to be sufficiently large to justify making only one pass through the data file, rather than the more statistical approach of doing many trials starting at random points in the data file.

The total potential data sample size, including the dead times between trails at 4800 b/s for 6 half hours per day, was 2.592×10^8 bits for the five-day sets of data and 7.776×10^8 bits for the 15-day set of data used in this paper.

To calculate delay distributions, a finite length message was assumed and delays incurred in the error-free delivery of this message were calculated for a variety of cases. To compare the improvement gained by FEC, we assumed a modulation scheme more amenable with FEC than DPSK, and signal levels adjusted as in the previous discussion on modulation.

On Julian days 210-225, 2215 messages (set 1) were collected at Thule AB. We shall consider this data along with 1353 messages (set 2) received at Sondrestrom AB and 931 messages (set 3) received at Thule AB on Julian days 277-282. All points are shown on the curves, and it can be seen from the smoothness of these curves that a statistically satisfactory sample of data was collected.

ARQ System Performance

In an ARQ system, a message of a given length can be transmitted successfully if there are no errors in it. An error causes a retransmission attempt. We calculated ARQ system performance by entering our meteor burst error patterns and simulating data transmission. Initially there are no errors, but as we progress into the lifetime of the meteor trail the error rate increases and our ability to communicate is limited. Eventually we must stop and wait for the next meteor trail.

In figures 3 through 5 the cumulative frequency of occurrence of messages of the stated length being delivered in at most the given time using ARQ is presented. The curve for a so-called one bit message actually shows the maximum possible number of messages deliverable in the given time. Figure 3 shows the results for set 1, the Thule AB data from Julian days 210 to 225 of 1986. The key feature to note is that while for short messages approximately 50 percent of deliveries took 30 seconds or less, for long messages this figure is 33 percent. Similarly, many more short messages are deliverable in a given time than long messages. The conclusion is that when using ARQ on a meteor burst channel, it is easier to deliver many short messages than a few long ones. At the ten minute point, where all messages have been delivered, the number of 40 bit messages delivered was 1726 while the number of 400 bit messages delivered was 682. This comparison points out that while first delivery is accomplished with short messages, the total amount of traffic delivered by long messages is approximately three times greater. Thus, if the user can wait he can eventually deliver more traffic using longer messages. For the data sample, the length of 400 to 500 bits/message is the maximum possible as at that point the ARQ system runs into significant numbers of channel errors and breaks down until a new meteor trail appears.

Figures 4 and 5 show the data sets for Thule AB and Sondrestrom AB for Julian days 277 to 282 of 1986. On these days a lesser percentage of messages were delivered in the first 30 seconds and a greater amount of traffic was delivered with long messages relative to short messages than was shown in figure 3. Thus, on these days meteor burst clearly would function best for the ARQ user who can wait a few minutes for the delivery of his traffic.

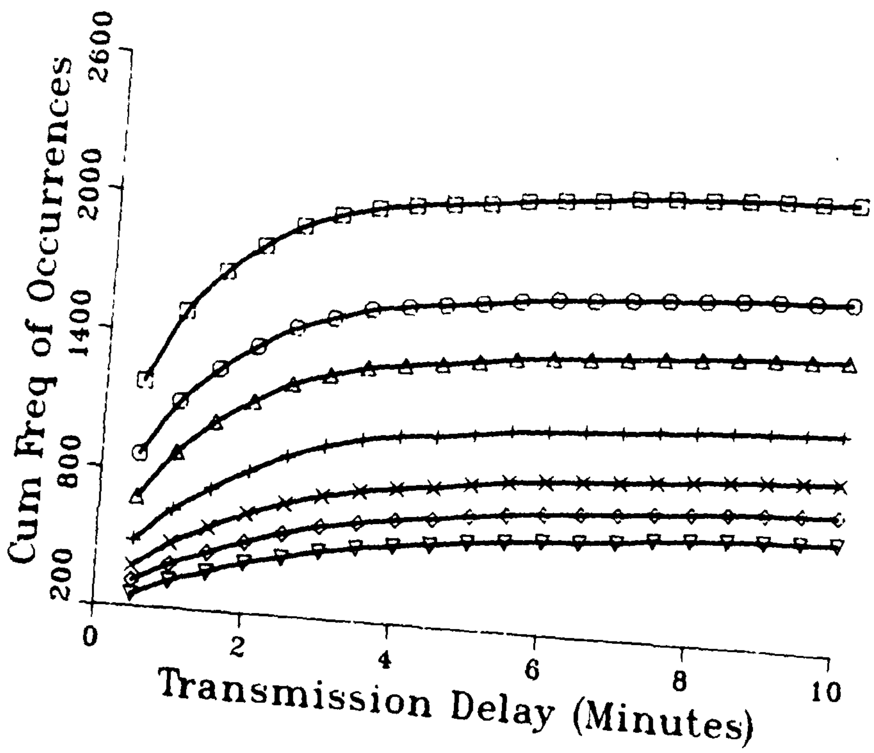

Figure 3. CUMULATIVE FREQUENCY OF OCCURRENCE OF MESSAGE DELIVERY IN AT MOST THE GIVEN TIME, SET 1 FOR MESSAGES OF LENGTH 1, 40, 80, 160, 240, 320 and 400 BITS, DENOTED BY □, ○, △, +, ×, ◇, and ▽ RESPECTIVELY.

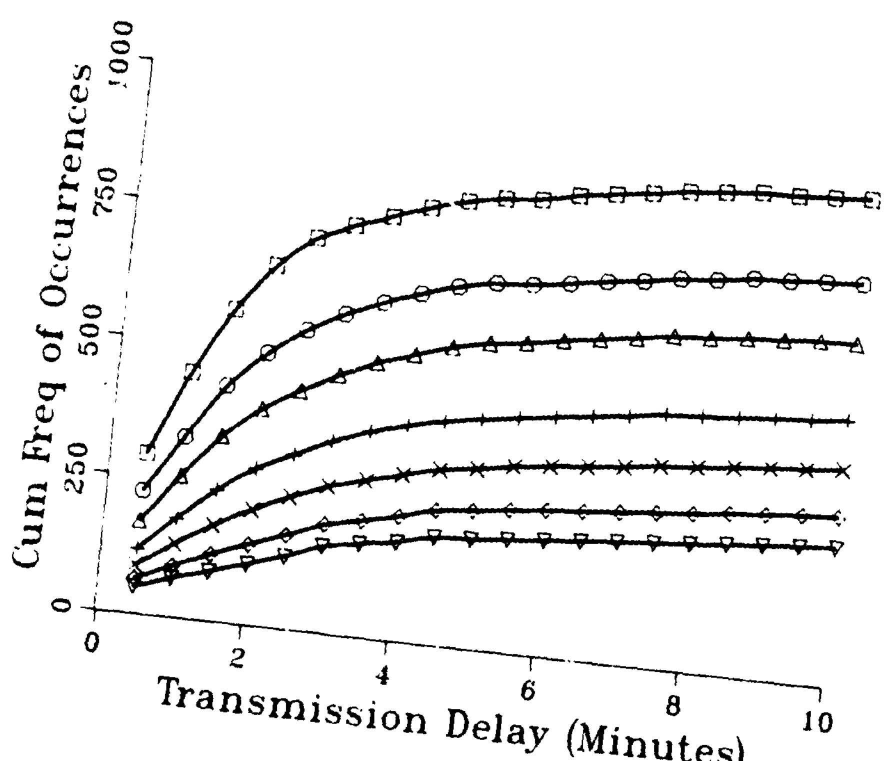

Figure 4. CUMULATIVE FREQUENCY OF OCCURRENCE OF MESSAGE DELIVERY IN AT MOST THE GIVEN TIME, SET 3 FOR MESSAGES OF LENGTH 1, 40, 80, 160, 240, 320 and 400 BITS, DENOTED BY □, ○, △, +, ×, , and ▽ RESPECTIVELY.

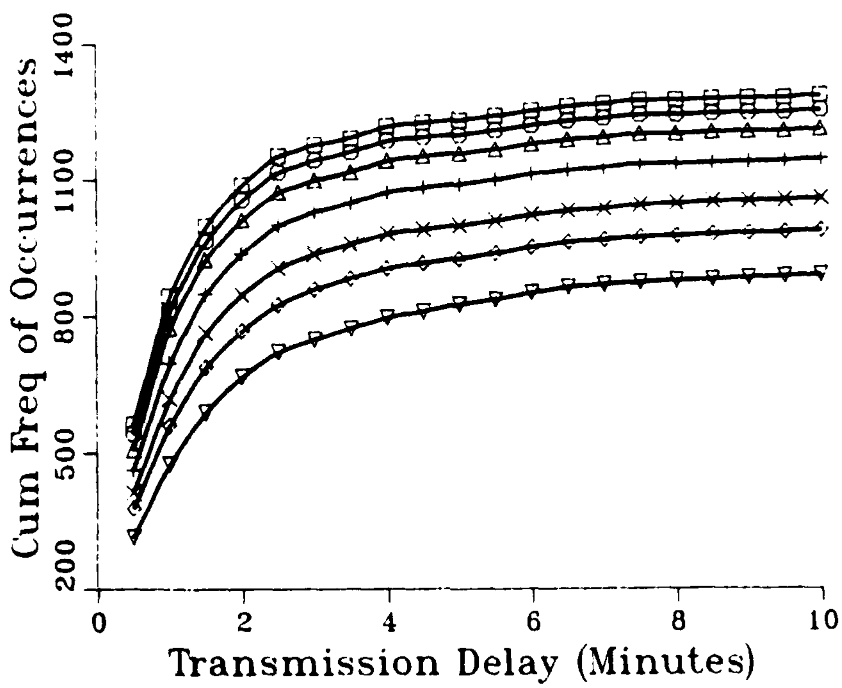

Figure 5. CUMULATIVE FREQUENCY OF OCCURRENCE OF MESSAGE DELIVERY IN AT MOST THE GIVEN TIME, SET 2 FOR MESSAGES OF LENGTH 1, 40, 80, 160, 240, 320 and 400 BITS, DENOTED BY □, ○, △, +, ×, ◇, and ▽ RESPECTIVELY.

Forward Error Correction Performance

Since the initial error-free portion of the meteor trail is followed by a region of random errors, it is postulated that some forward error correction coding applied prior to retransmission could create a longer period of time through which this hybrid system could function, thus delivering a greater total amount of traffic. We have chosen to consider for the same data sets a group of 63 bit BCH codes [(n,k),t] identified as follows: [(63,57),1], [(63,51),2], [(63,45),3], [(63,39),4], [(63,36),5]. We have again examined message lengths of 40, 80, 160, 240, 320, and 400 bits.

Comparing the data on figure 6 with that on figure 3 it can be seen that use of the [(63,57),1] code improves performance at all message lengths at 30 seconds and for all but the 400 bit message at 10 minutes.

For the other codes, as can be seen by comparing figures 7 through 10 to figure 3, the improvement is for all delivery times. However, it should also be clear that these higher orders of coding correcting more errors at a penalty of fewer information bits transmitted, do not gain significantly over the first code. Thus a small amount of forward error correction will significantly improve the ARQ system performance.

Figures 11 through 15 show a variation from slight i rovement to slight degradation with coding. On this link the coding apparently made little difference. We do, however, note that this link had a 5 dB advantage in SNR at the Sondrestrom end. This resulted in a greater number of error-free messages being received, although those that had errors were not as amenable to coding as those received at the Thule end. Coding will gain up to 3.9 dB depending upon the code. Thus, what actually happened in this link is that the coding made up most of the signal-to-noise degradation on the channel.

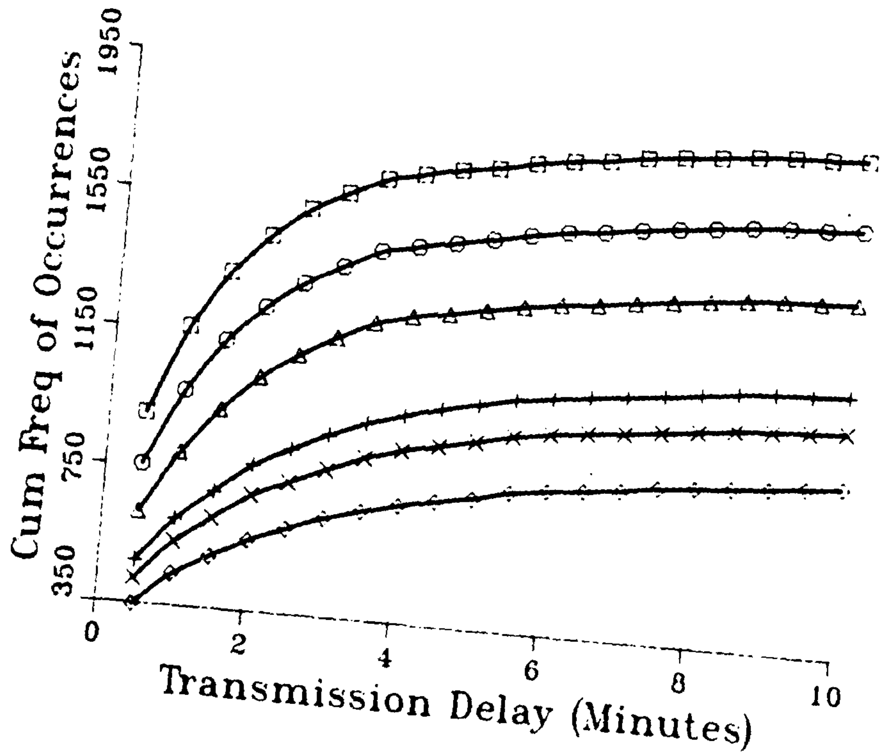

Figure 6. CUMULATIVE FREQUENCY OF OCCURRENCE OF MESSAGE DELIVERY IN AT MOST THE GIVEN TIME, SET 1, [(63, 57), 1] CODE, MESSAGE LENGTHS 40, 80, 160, 240, 320 and 400 BITS, DENOTED AS □, ○, △, +, ×, and ◇ RESPECTIVELY.

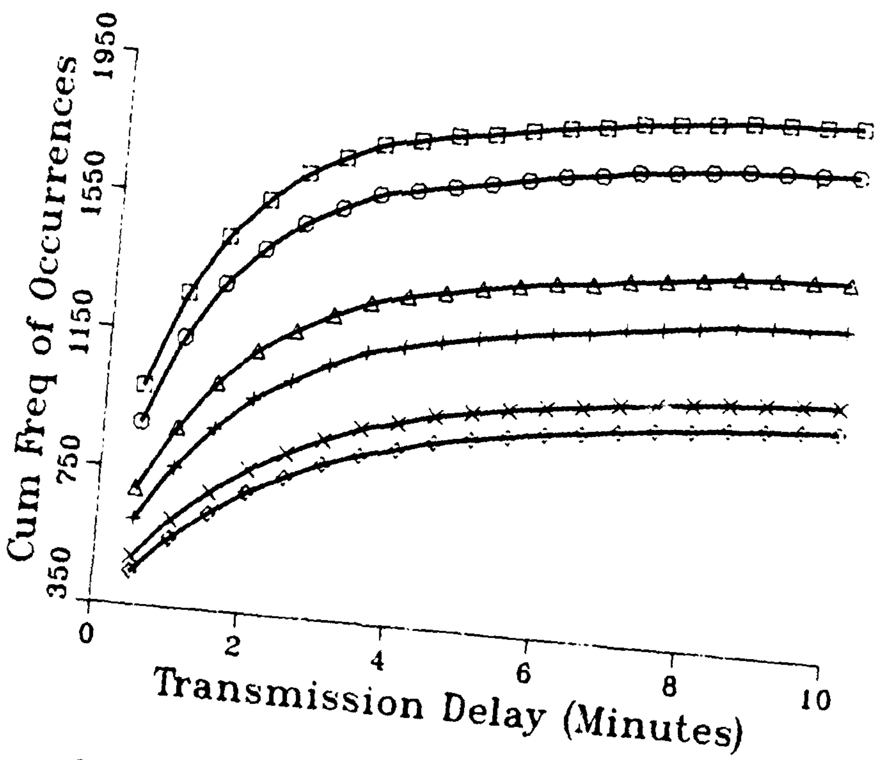

Figure 7. CUMULATIVE FREQUENCY OF OCCURRENCE OF MESSAGE DELIVERY IN AT MOST THE GIVEN TIME, SET 1, [(63, 51), 2] CODE, MESSAGE LENGTHS 40, 80, 160, 240, 320 and 400 BITS, DENOTED AS □, ○, △, +, ×, and RESPECTIVELY.

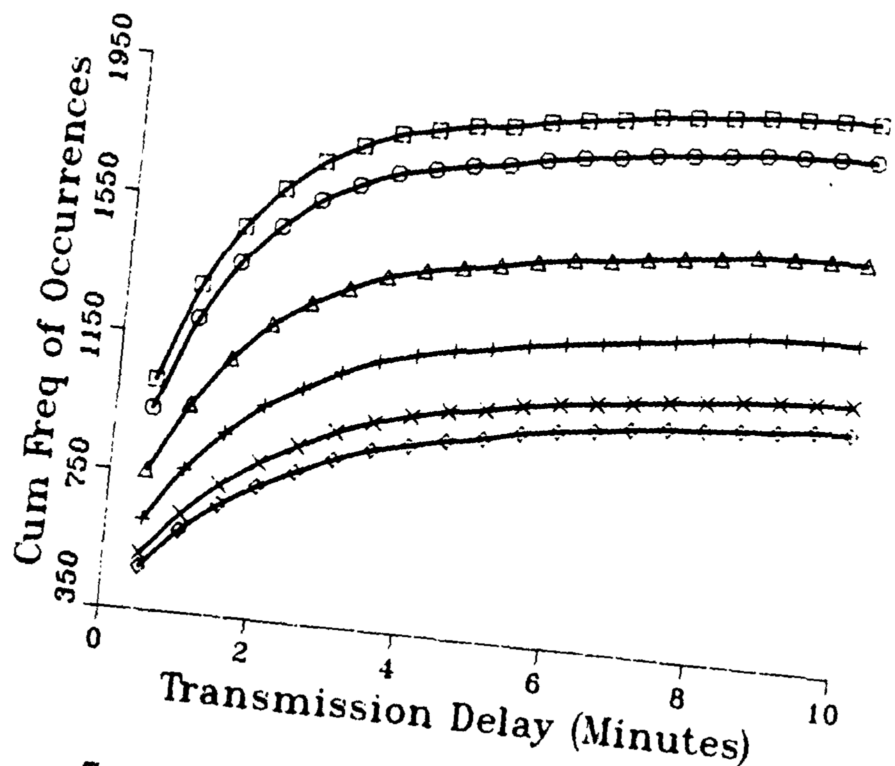

Figure 8. CUMULATIVE FREQUENCY OF OCCURRENCE OF MESSAGE DELIVERY IN AT MOST THE GIVEN TIME, SET 1, [(63, 45), 3] CODE, MESSAGE LENGTHS 40, 80, 160, 240, 320 and 400 BITS, DENOTED AS □, ○, △, +, x, and ◇ RESPECTIVELY.

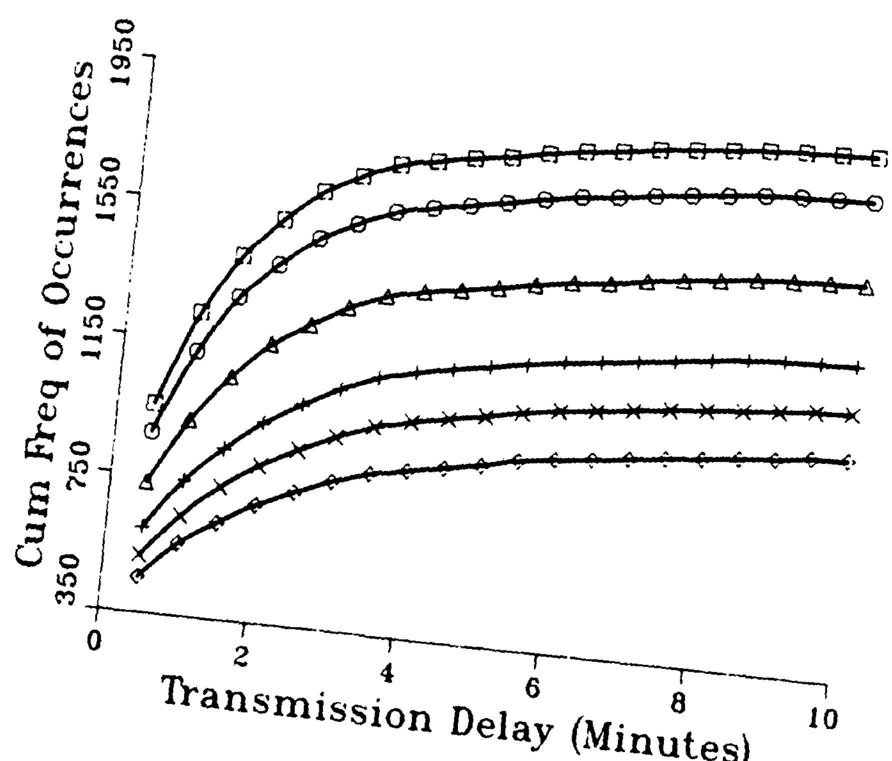

Figure 9. CUMULATIVE FREQUENCY OF OCCURRENCE OF MESSAGE DELIVERY IN AT MOST THE GIVEN TIME, SET 1, [(63, 39), 4] CODE, MESSAGE LENGTHS 40, 80, 160, 240, 320 and 400 BITS, DENOTED AS □, ○, △, +, ×, and ◇ RESPECTIVELY.

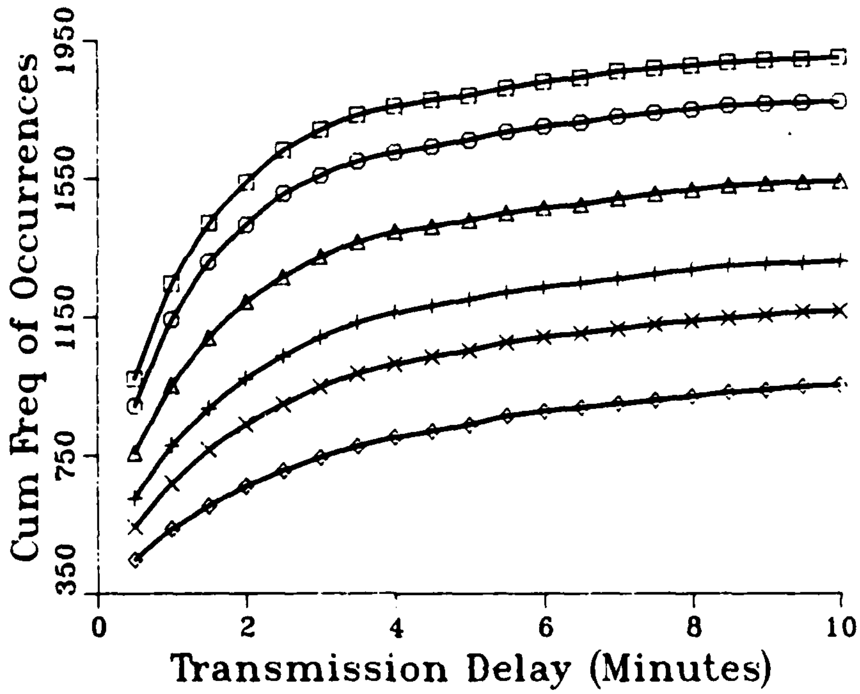

Figure 10. CUMULATIVE FREQUENCY OF OCCURRENCE OF MESSAGE DELIVERY IN AT MOST THE GIVEN TIME, SET 1, [(63, 36), 5] CODE, MESSAGE LENGTHS 40, 80, 160, 240, 320 and 400 BITS, DENOTED AS □, ○, △, +, x, and ◇ RESPECTIVELY.

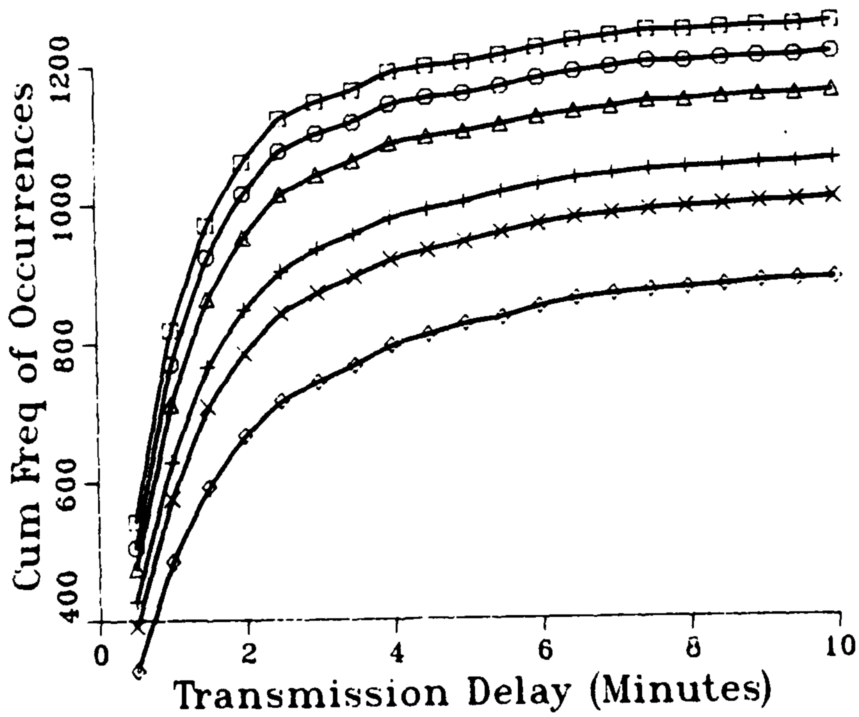

Figure 11. CUMULATIVE FREQUENCY OF OCCURRENCE OF MESSAGE DELIVERY IN AT MOST THE GIVEN TIME, SET 2, [(63, 57), 1] CODE, MESSAGE LENGTHS 40, 80, 160, 240, 320 and 400 BITS, DENOTED AS □, ○, △, +, ×, and RESPECTIVELY.

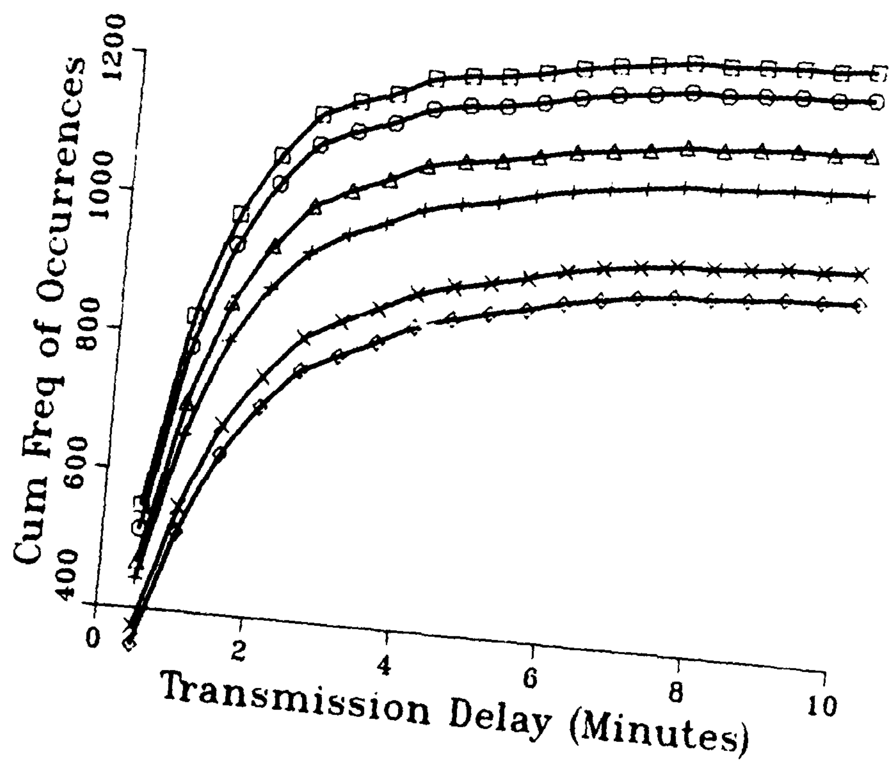

Figure 12. CUMULATIVE FREQUENCY OF OCCURRENCE OF MESSAGE DELIVERY IN AT MOST THE GIVEN TIME, SET 2, [(63, 51), 2] CODE, MESSAGE LENGTHS 40, 80, 160, 240, 320 and 400 BITS, DENOTED AS □, ○, △, +, x, and ◇ RESPECTIVELY.

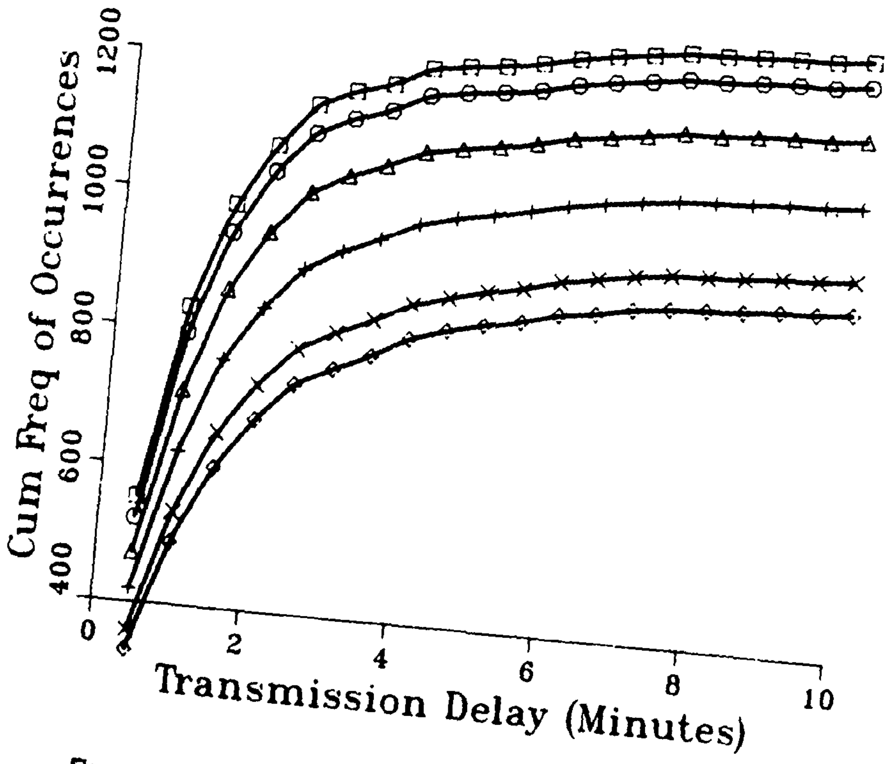

Figure 13. CUMULATIVE FREQUENCY OF OCCURRENCE OF MESSAGE DELIVERY IN AT MOST THE GIVEN TIME, SET 2, [(63, 45), 3] CODE, MESSAGE LENGTHS 40, 80, 160, 240, 320 and 400 BITS, DENOTED AS □, ○, △, +, ×, and ◇ RESPECTIVELY.

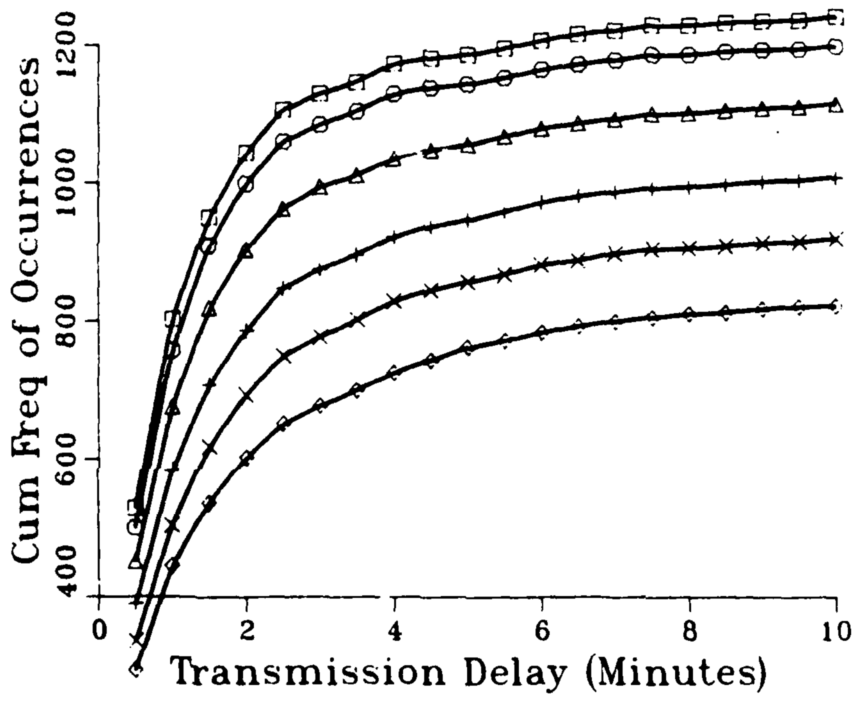

Figure 14. CUMULATIVE FREQUENCY OF OCCURRENCE OF MESSAGE DELIVERY IN AT MOST THE GIVEN TIME, SET 2, [(63, 39), 4] CODE, MESSAGE LENGTHS 40, 80, 160, 240, 320 and 400 BITS, DENOTED AS □, ○, △, +, ×, and ◇ RESPECTIVELY.

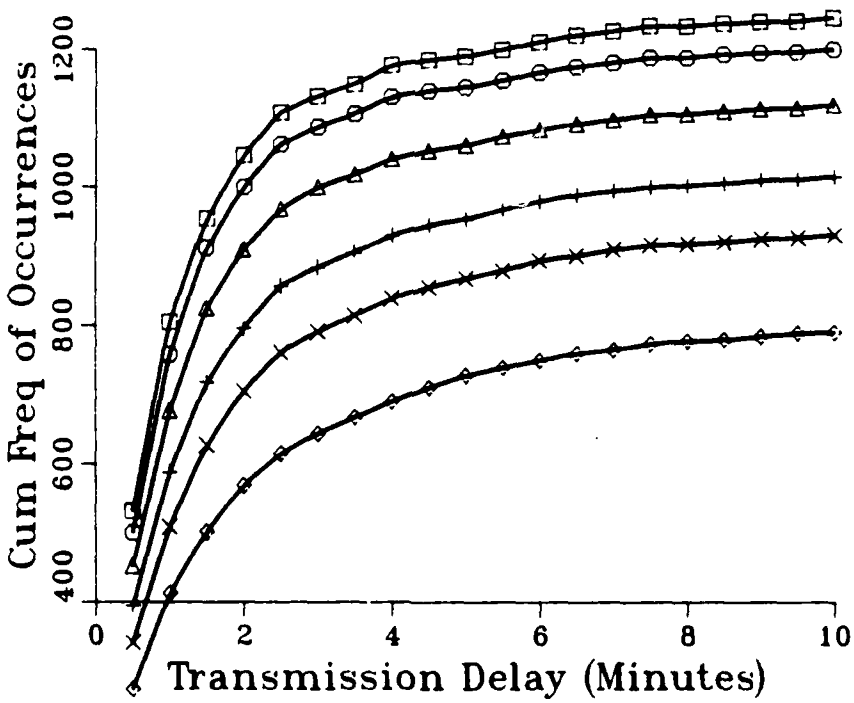

Figure 15. CUMULATIVE FREQUENCY OF OCCURRENCE OF MESSAGE DELIVERY IN AT MOST THE GIVEN TIME, SET 2, [(63, 36), 5] CODE, MESSAGE LENGTHS 40, 80, 160, 240, 320 and 400 BITS, DENOTED AS □, ○, △, +, x, and ◇ RESPECTIVELY.

Figures 16 through 20 when compared to figure 6 show similar results to those previously seen at the Thule AB site. Some coding will definitely improve the performance of an ARQ system by correcting the first few random errors after the opening error-free interval.

An interesting result is shown in figures 21 and 22. This is the same data as shown in figures 16 through 20, highlighting the fact that performance improves with coding as more errors are corrected until the penalty of overhead takes over and performance decreases. For the short message, the t=3 code gave the best performance. For the long message, t=2 was best with t=3 only slightly poorer.

The curves clearly show that larger volumes of traffic can progress on the meteor burst link if longer messages are sent and greater waiting times for delivery are permitted when employing a Hybrid FEC-ARQ system architecture. The curves also show that a little coding will go a long way and a system designer can reduce performance if too much coding is employed.

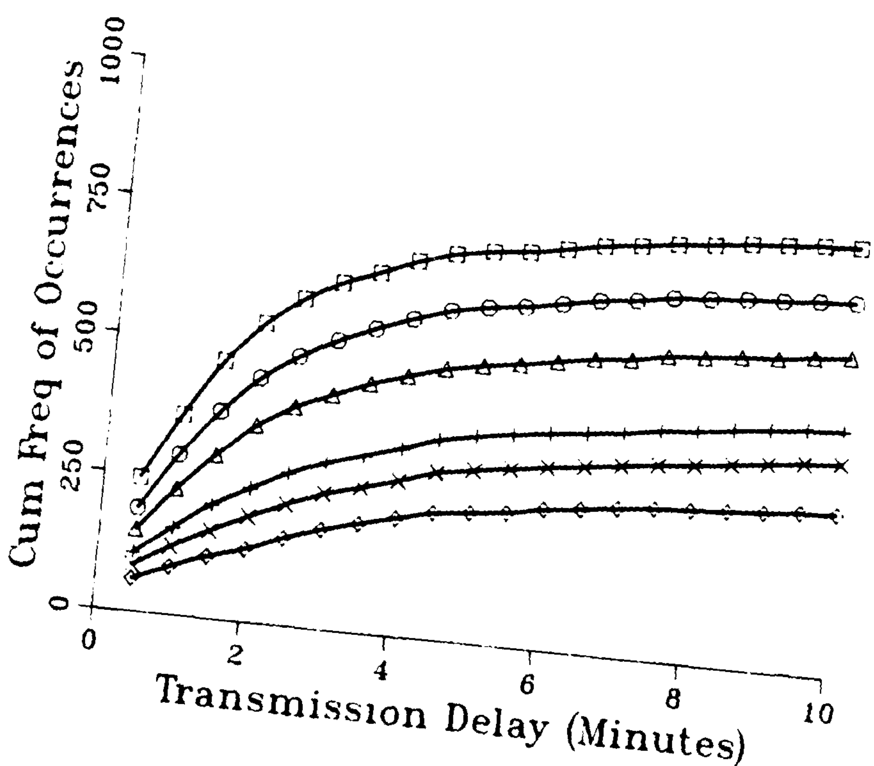

Figure 16. CUMULATIVE FREQUENCY OF OCCURRENCE OF MESSAGE DELIVERY IN AT MOST THE GIVEN TIME, SET 3, [(63, 57), 1] CODE, MESSAGE LENGTHS 40, 80, 160, 240, 320 and 400 BITS, DENOTED AS □, ○, △, +, x, and ◇ RESPECTIVELY.

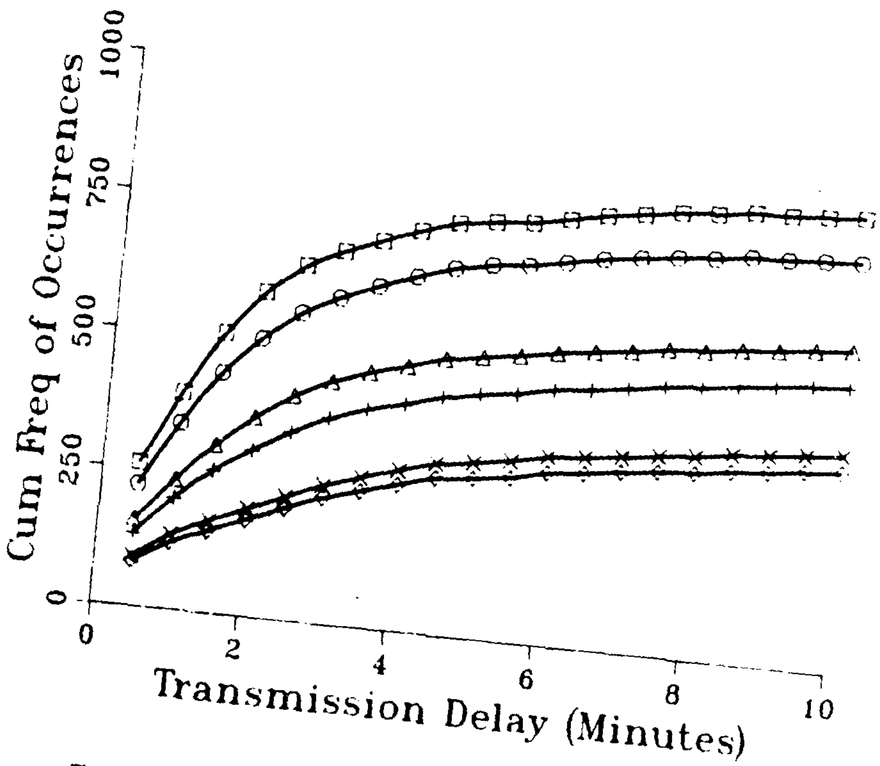

Figure 17. CUMULATIVE FREQUENCY OF OCCURRENCE OF MESSAGE DELIVERY IN AT MOST THE GIVEN TIME, SET 3, [(63, 51), 2] CODE, MESSAGE LENGTHS 40, 80, 160, 240, 320 and 400 BITS, DENOTED AS □, ○, △, +, ×, and ◇ RESPECTIVELY.

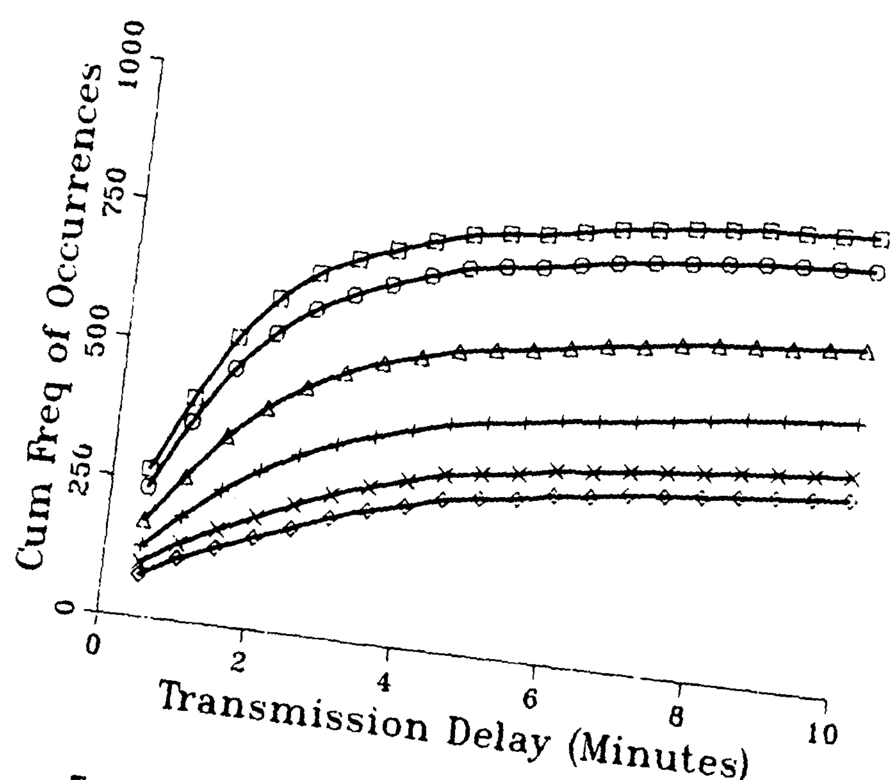

Figure 18. CUMULATIVE FREQUENCY OF OCCURRENCE OF MESSAGE DELIVERY IN AT MOST THE GIVEN TIME, SET 3, [(63, 45), 3] CODE, MESSAGE LENGTHS 40, 80, 160, 240, 320 and 400 BITS, DENOTED AS □, ○, △, +, ×, and ◇ RESPECTIVELY.

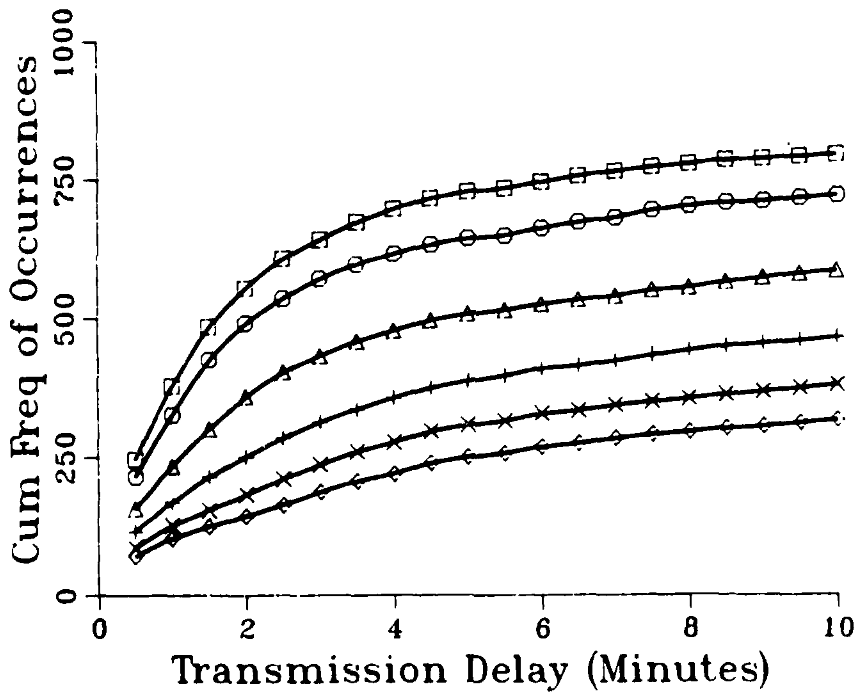

Figure 19. CUMULATIVE FREQUENCY OF OCCURRENCE OF MESSAGE DELIVERY IN AT MOST THE GIVEN TIME, SET 3, [(63, 39), 4] CODE, MESSAGE LENGTHS 40, 80, 160, 240, 320 and 400 BITS, DENOTED AS □, ○, △, +, x, and ◇ RESPECTIVELY.

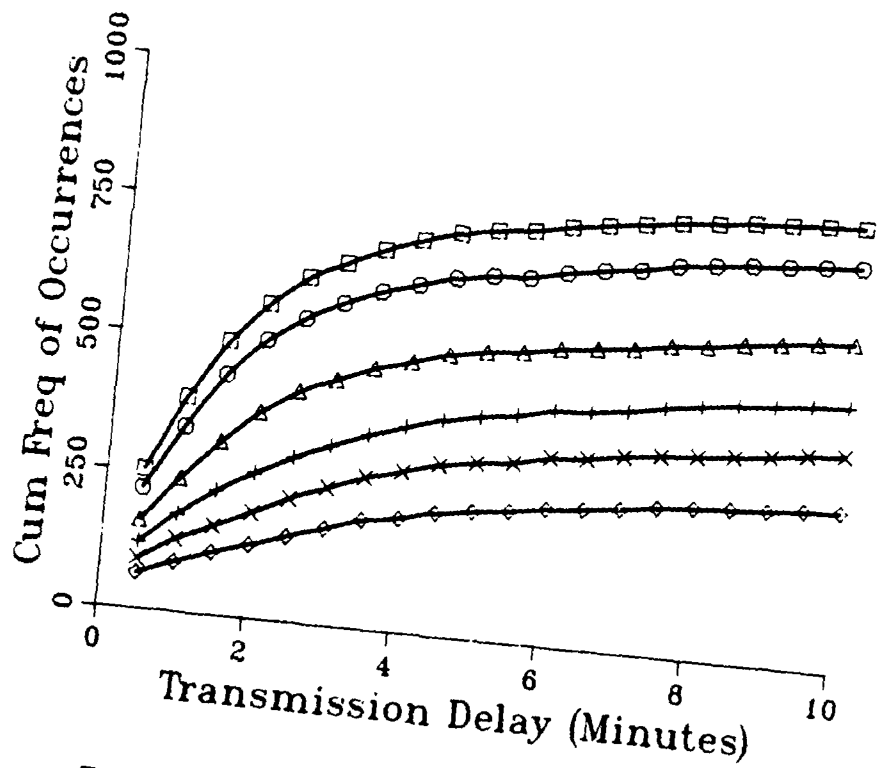

Figure 20. CUMULATIVE FREQUENCY OF OCCURRENCE OF MESSAGE DELIVERY IN AT MOST THE GIVEN TIME, SET 3, [(63, 36), 5] CODE, MESSAGE LENGTHS 40, 80, 160, 240, 320 and 400 BITS, DENOTED AS □, ○, △, +, x, and ◇ RESPECTIVELY.

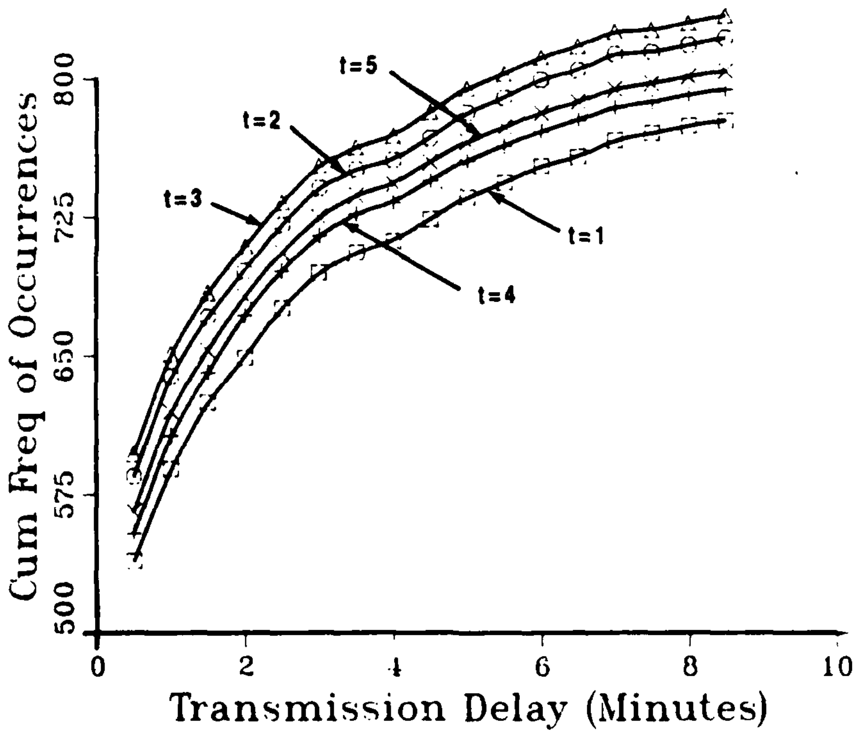

Figure 21. CUMULATIVE FREQUENCY OF OCCURRENCE OF MESSAGE DELIVERY IN AT MOST THE GIVEN TIME FOR A 40 BIT MESSAGE, SET 3.

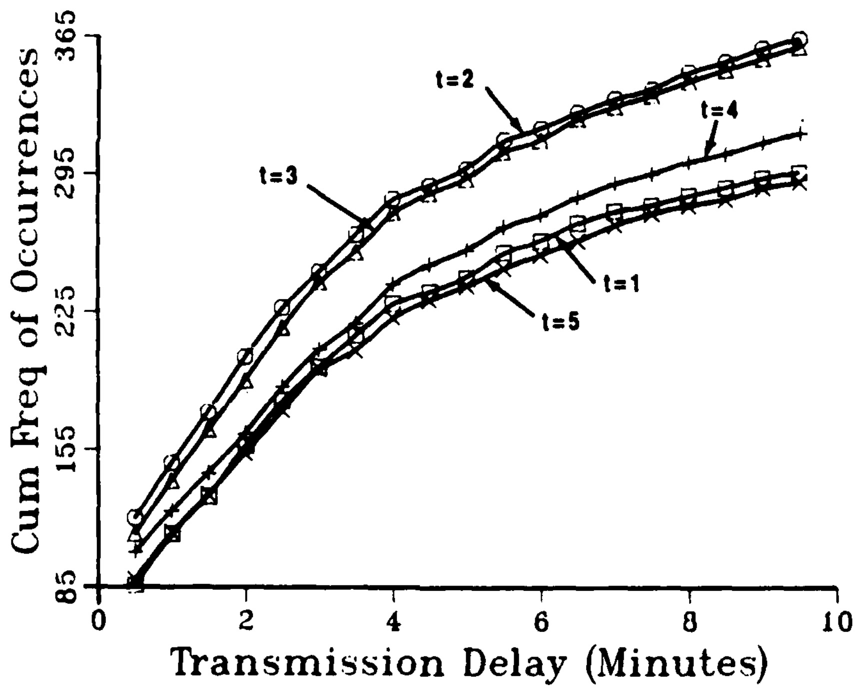

Figure 22. CUMULATIVE FREQUENCY OF OCCURRENCE OF MESSAGE DELIVERY IN AT MOST THE GIVEN TIME FOR A 400 BIT MESSAGE, SET 3.

SECTION 5

CONCLUSION

An examination of the performance of a modified commercial communication system on an experimental meteor burst channel has been made. It has been shown that an ARQ system will function early in a trail where there are no errors. This is no news since it is exactly how current systems operate. By adding forward error correction, the initial errors that occur after the first error-free gap can be corrected and the time duration of operation can be extended. While it takes 10 minutes to reach a maximum probability of traffic delivery, a significant portion of traffic (circa 40 percent) can be delivered in the first 30 seconds after an attempt.

Meteor burst communication, while not suited for transmission of long messages or rapid delivery of data, can be useful for those in remote areas or those who can accept a mailgram type of service.

LIST OF REFERENCES

1. Crane, Peter C., "An Empirical Analysis of the Application of Forward Error Correction to Meteor Burst Communications," IEEE MILCOM '88, San Diego, CA, October 1988.

2. Brayer, Kenneth, "ARQ and Hybrid FEC-ARQ System Design to Meet Tight Performance Constraints," National Telecommunications Conference, Dallas, TX, November 1976.

3. Peterson, W. Wesley, and E. J. Weldon, Jr., Error-Correcting Codes, 2nd ed., MIT Press, 1972.

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